The Grass Carp Stocking Rate Model (AMUR/STOCK)

PURPOSE: The AMUR/STOCK model is a coupled plant growth and fish feeding and bioenergetics simulation model that evaluates the effectiveness of grass carp stocking rate strategies for controlling nuisance growth of aquatic plants under user-selected site conditions. This technical note (TN) describes the major components and some of the major assumptions of this simulation tool, and demonstrates the intended use of the model for evaluating proposed stocking rate strategies.

BACKGROUND: Grass carp have proven an effective control of nuisance aquatic plant growth since their introduction into the United States in 1963 (Guillory and Gassaway 1978). Grass carp were initially banned from many states due to the potential ecological risk associated with releasing reproductively viable diploid variants (Stanley, Miley, and Sutton 1978). However, even after reliable triploid inducement techniques were developed that produce sterile fish for release programs (Cassani and Caton 1986), many states still banned or restricted grass carp use (Allen and Wattendorf 1987).

Part of the reason for continued restrictions on grass carp concerns uncertainty in determining stocking strategies that provide desired control levels without risking unwanted impacts (Noble, Bertolli, and Bestill 1986; Leslie et al. 1987). Table 1 illustrates the extreme variability in stocking rates that have been used under different conditions. Factors accounting for variability in reported stocking rates include control objectives, waterbody characteristics (e.g. size, seasonal temperatures), plant infestation growth characteristics (e.g. plant species, overwintering level, regrowth rate, peak density), and grass carp stocking size, mortality, and feeding and dispersal behavior.

Table 1
Reported Grass Carp Stocking Rates for Aquatic Vegetation Control in U.S. Waterbodies

Source	State	Stocking Rate
Sutton and Vandiver (1986)	Florida	3 - 638 fish/veg hec
Leslie et al. (1987)	Florida	9 - 440 fish/veg hec
TVA (1990)	Alabama	17 fish/veg hec
Dekozlowski (1994)	South Carolina	37 fish/veg hec
Santha et al. (1991)	Texas	79 - 130 fish/veg hec
Wiley et al. (1987)	Illinois	47 - 370 fish/veg hec
Bonar et al. (1993)	Oregon	180 fish/veg hec
Hoyer and Canfield (1997)	Numerous	20 - 150 fish/veg hec

Individual site conditions and control objectives, including desired effect time, must be considered to determine proper stocking rates. This is especially important since grass carp are long-lived and difficult to remove after stocking (Leslie et al. 1987, Klussman et al. 1988). To determine proper stocking rates, several computer models have been developed by various state and federal agencies in the past (Miller and Decell 1984, Swanson and Bergersen 1988, Wiley et al. 1984, Boyd and Stewart 1990, Santha et al. 1991). Each of these models represents a simplified account of the overall processes that interact within this complex biocontrol system. However, through exercise of these tools, aquatic plant control decision makers are able to pose "What if" type questions regarding grass carp use under environmental and biotic conditions representative of their waterbody and plant control needs.

MODEL DESCRIPTION: The AMUR/STOCK model described herein is based in part on an earlier model developed by WES (Miller and Decell 1984) and on the energy balances reported for grass carp by Wiley and Wike (1986). The AMUR/STOCK model has separate routines for generating daily estimates of plant biomass and for estimating the size and remaining number of grass carp.

Plant Growth Module. The plant growth simulation module calculates a daily update in biomass level by adjusting the previous daily biomass level for the daily growth increment, the daily mortality increment (i.e. other than grass carp herbivory), and the daily grass carp herbivory increment. This relationship is expressed as:

$$\text{Biomass Level}_{\text{current}} = \text{Biomass Level}_{\text{previous}} + DG - DM - DH \tag{1}$$

where

DG = daily growth increment
DM = daily mortality increment
DH = daily herbivory increment

Daily growth increments in plant biomass for the target plant population are calculated by making seasonal and site condition adjustments to an assumed maximum daily relative growth rate. In the model, the maximum relative growth rate is set at 0.05. Actual daily growth rates are calculated by correction factors (1.0 to 0.0) that account for the affects of season, plant biomass level (i.e., as a ratio of the current biomass level to the site carrying capacity or maximum biomass level), and grass carp herbivory.

$$\text{Daily growth increment} = \text{Biomass Level}_{\text{previous}} * \{RGR_{max} * G_{season} * G_{biomass} * G_{herbivory}\} \tag{2}$$

where

RGR_{max} = maximum relative growth rate
G_{season} = seasonal adjustment
$G_{biomass}$ = site carrying capacity adjustment
$G_{hervivory}$ = herbivory adjustment

Under sustained growth at the maximum relative growth rate with no daily losses, the plant biomass would double in approximately 14 days. For comparison, doubling times for relative growth rates less than the maximum rate are illustrated in Figure 1.

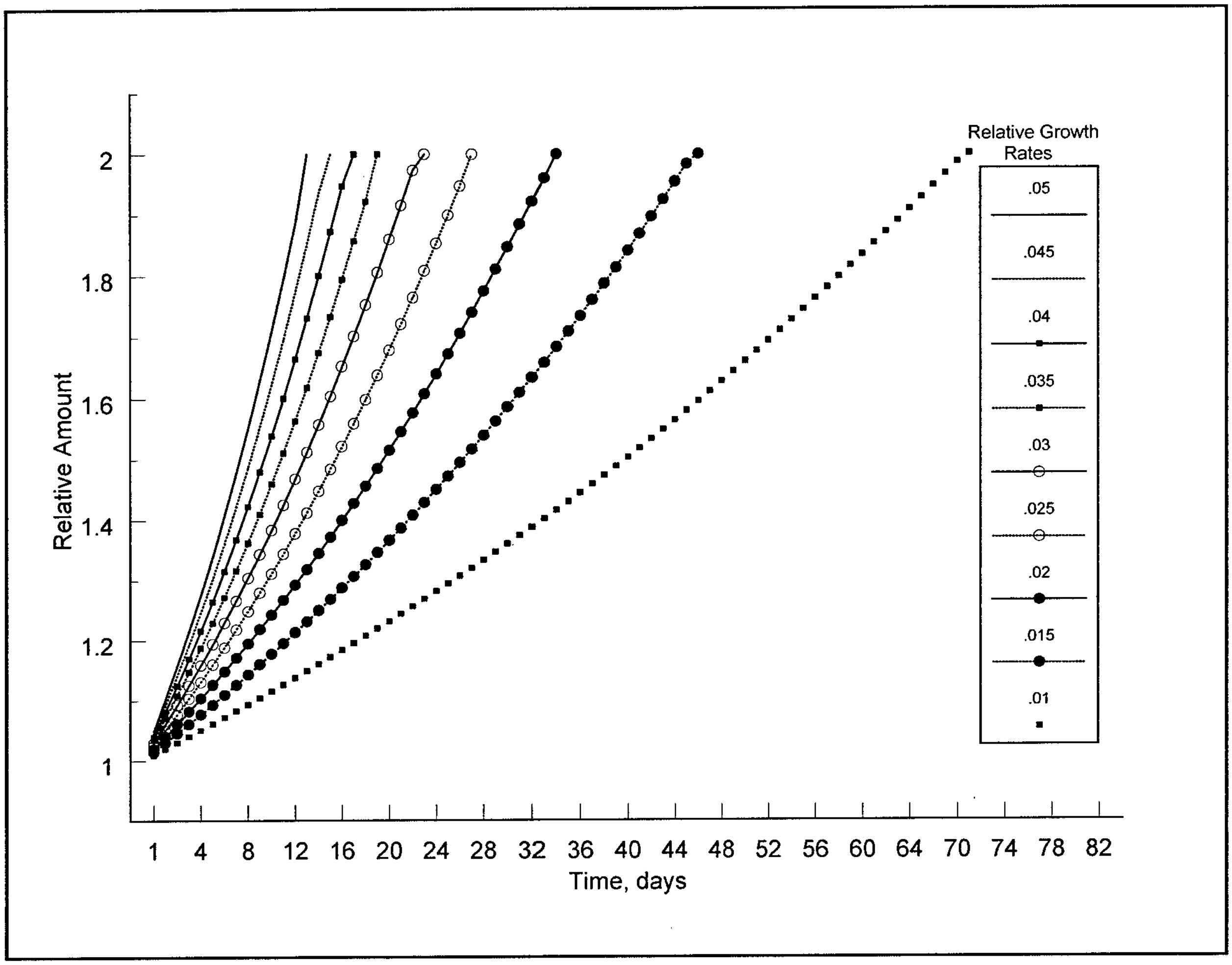

Figure 1. "Doubling time" for nine relative growth rates (RGRs). Doubling time refers to the time required for a relative amount to increase in value from 1.0 to 2.0

Daily mortality estimates are also calculated by adjusting the maximum relative mortality rate, set at 0.05 in the model, for assumed effects of season, and plant density level. Actual daily biomass losses due to grass carp herbivory are calculated as described below.

Fish Bioenergetics Module. Daily plant consumption by grass carp is determined by the number of grass carp remaining and relationships that consider the average size of fish, temperature, and plant species. Daily fish growth is calculated from the daily consumption amount, which is adjusted to account for assimilation efficiency of consumed plant material and fish metabolic costs. Assimilation efficiency is also a function of fish size and temperature. Fish metabolic costs are subtracted from the assimilated amount. All calculations in the fish bioenergetics module are based on energy content (joules) of aquatic plants. Final conversion of net energy intake into fish biomass is a function of fish size and temperature. Reductions to the number of fish are made at the end of each year of the simulation period. Yearly mortality estimates can be input by the user, or the model can be run using a default mortality setting of 10 percent per year.

Daily ingestion. Daily ingestion of fresh plant material by individual fish is initially estimated as a percent of the fish body weight. Values shown in Figure 2 were derived from estimates included in Wiley and Wike (1986) and have been adjusted to feeding by diploid fish at 25 °C. In the model,

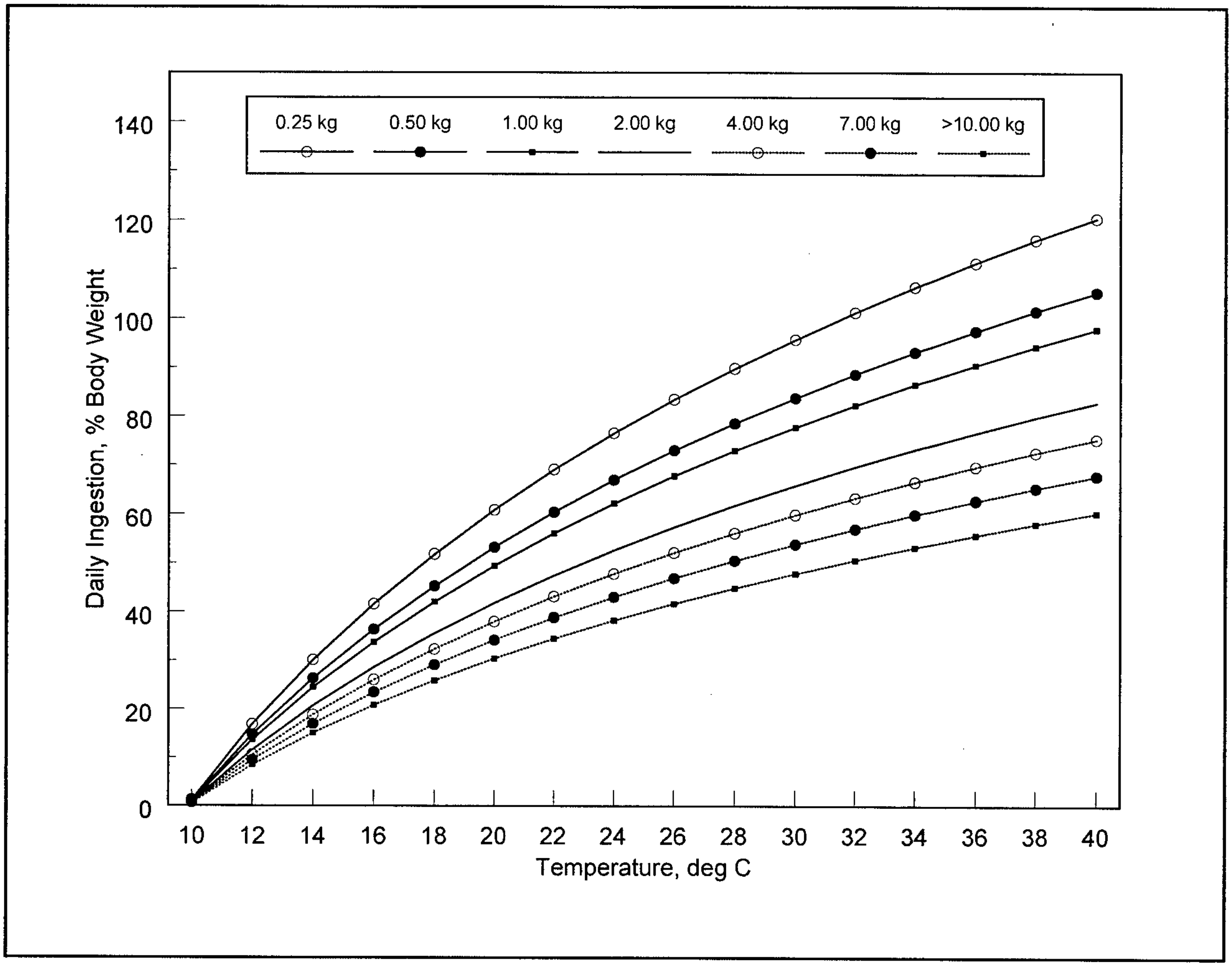

Figure 2. Relationship of grass carp daily consumption to fish body size and temperature. In the model, daily consumption is calculated as a percent of fish body weight

the percent body weight value is then adjusted for the actual daily temperature by one of the following temperature correction factors (TC):

Diploid fish

$$TC = -2.4596 + 1.07480 * \log_e(T) \tag{3}$$

Triploid fish

$$TC = -2.8491 + 1.19889 * \log_e(T) \tag{4}$$

Hybrid fish

$$TC = -4.0873 + 1.58047 * \log_e(T) \tag{5}$$

where, T = water temperature (^{o}C).

The simulation allows additional adjustments to daily ingestion for plant preference (Table 2) and fish genetic variant. For moderately preferred target plant species, daily ingestion is reduced to 75 percent of the model-calculated value from above, which is based on ingestion rates of highly preferred species. For non-preferred plant species, daily ingestion is reduced to 67 percent of the model-calculated value. Based on comparative studies reported by Wiley and Wike (1986), daily ingestion for triploid and hybrid fish is estimated as 90 and 67 percent, respectively, of diploid fish.

Table 2
Grass Carp Feeding Preferences[1] for Common Aquatic Plants

Preference	Scientific Name	Common Name
Highly preferred	*Cabomba caroliniana*	Fanwort
	Chara spp.	Muskgrass
	Egeria densa	Brazilian elodea
	Elodea canadensis	Common elodea
	Hydrilla verticillata	Hydrilla
	Lemna spp. and *Spirodela* spp.	Duckweeds
	Najas quadalupensis	Southern naiad
Moderately preferred	*Azolla caroliniana*	Azolla or water-fern
	Bacopa spp.	Water hyssop
	Eleocharis spp.	Slender spikerush
	Potamogeton spp.	Pondweeds
	Utricularia spp.	Bladderworts
Non-preferred	*Ceratophyllum demersum*	Coontail
	Myriophyllum spp.	Milfoils
	Brasenia schreberi	Water shield
	Nuphar spp.	Spatterdock
	Nymphaea spp.	Waterlillies
	Vallisneria americana	Tapegrass or eel-grass
	Nelumbo luteum	Lotus

[1] Compiled from Sutton and Vandiver (1986), Miller and Decell (1984), Wiley et al. (1984), and others.

Ingested plant mass (fresh weight) is converted to a daily "energetic" intake (joules) by using an estimated conversion factor of 1,500 joules per gram of plant fresh weight. This value approximates a median conversion factor for different plant species as reported by Wiley and Wike (1986).

Assimilation efficiency. Of the ingested material, Wiley and Wike (1986) report that grass carp in general assimilate only a small proportion of their daily intake. Based on results of their studies, assimilation efficiency (percent) is calculated in the model by the following equation:

$$\text{Assimilation efficiency (\%)} = -0.026 - 0.058 \log_e W + 0.213 \log_e T \qquad (6)$$

As illustrated in Figure 3, assimilation efficiency is directly related to temperature and inversely to fish body size.

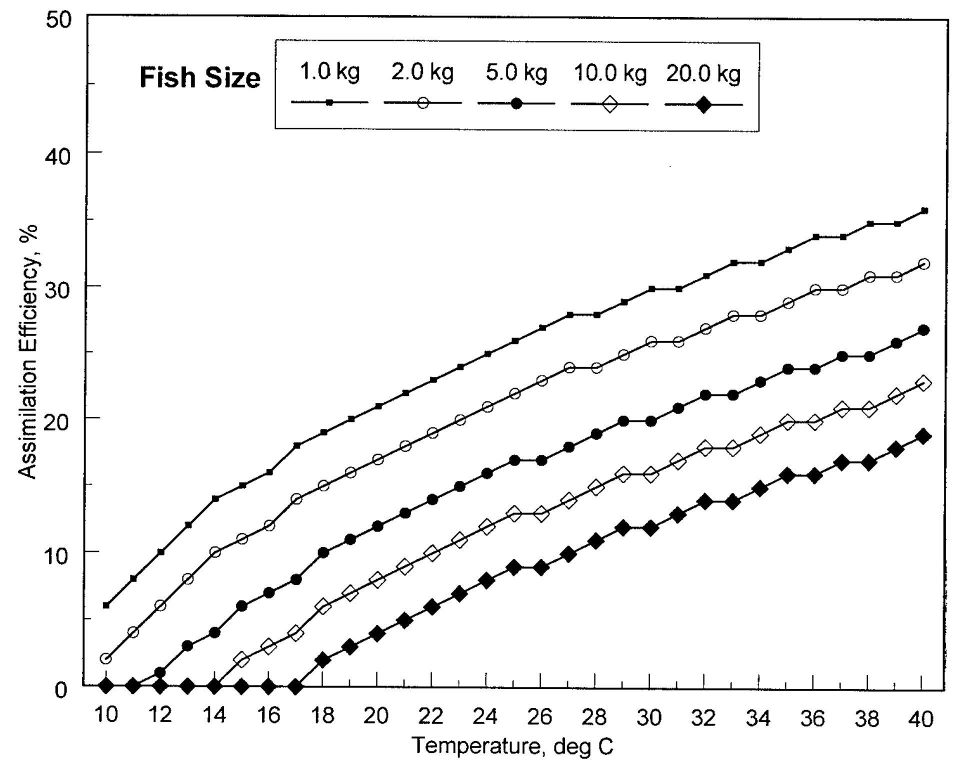

Figure 3. Relationship of grass carp assimilation efficiency (% of consumption) to fish body size and temperature

Metabolic costs. Total daily metabolic costs (TDMC) of individual fish are assumed to be comprised of standard metabolism, active metabolism, and specific dynamic action. Standard metabolic rate (SMR) for grass carp was shown by Wiley and Wike (1986) to be related to temperature and body weight by the following equation:

$$SMR = 0.026 * W^{0.645} * T^{1.07} \qquad (7)$$

where

W = average fish weight, grams live weight
T = daily water temperature, °C

The units for standard metabolic rate in Equation 7 are mg O_2 per hour, and are converted to a daily standard metabolic cost (DSMC), in units of joules per day, by Equation 8.

$$DSMC(j/d) = mgO_2/hr * 24\ hr/day * 4.6\ cal/mgO_2 * 4.184\ j/c \qquad (8)$$

where

4.6 = an estimate of the caloric cost of respiration for herbivorous fish
4.184 = conversion factor from calories to joules

Daily metabolic cost of activity (DMCA) is calculated in the model by correcting the DSMC for temperature and the active period of the day by the following equation:

$$DMCA\ (j/d) = DSMC * TC * 0.67 \qquad (9)$$

where

TC = a temperature correction coefficient calculated previously at Equations 3-5
0.67 = an estimate of the daily active period (16 hr)

The final component of total daily metabolic costs is included to estimate metabolic costs associated with food ingestion. Termed specific dynamic action, or SDA, this cost was estimated by Wiley and Wike (1986) at 7 percent of daily ingestion.

Collectively, the above equations are responsible for determining the proportions of daily consumption that are allotted to egestion (i.e. excretion + defecation = 1.0 - assimilation), metabolic cost, and growth. Figure 4 illustrates bioenergetic balances for four size classes of grass carp feeding at three different temperatures. As general rules, note that the proportions of consumption that are available for growth are inversely related to fish size and directly related to temperature.

MODEL APPLICATION PROCEDURES. The first step in the initialization process is input of the simulation period (1 to 10 years). The next input is a water temperature data set for the water body in question. If a temperature data set is not available to the user, the model can be initialized with one of several default data sets included with the software package. Next, the user is prompted to provide a series of inputs that provide calibration of the plant growth module for the plant infestation in question. This is a two-step process that first involves initializing the module for the plant species, the overwintering plant biomass level, and the peak plant biomass level. These biomass estimates should be provided from field measurements if possible. Next the user specifies one of three seasonal plant growth calibration data sets that will be utilized for the simulation run. Plant growth calibration data sets included with the model produce plant growth curves that provide one of the following: (1) a normal growth curve, with "spring regrowth" initiated in May, (2) a modified growth curve, with regrowth delayed until June, or (3) a growth curve with regrowth delayed until July.

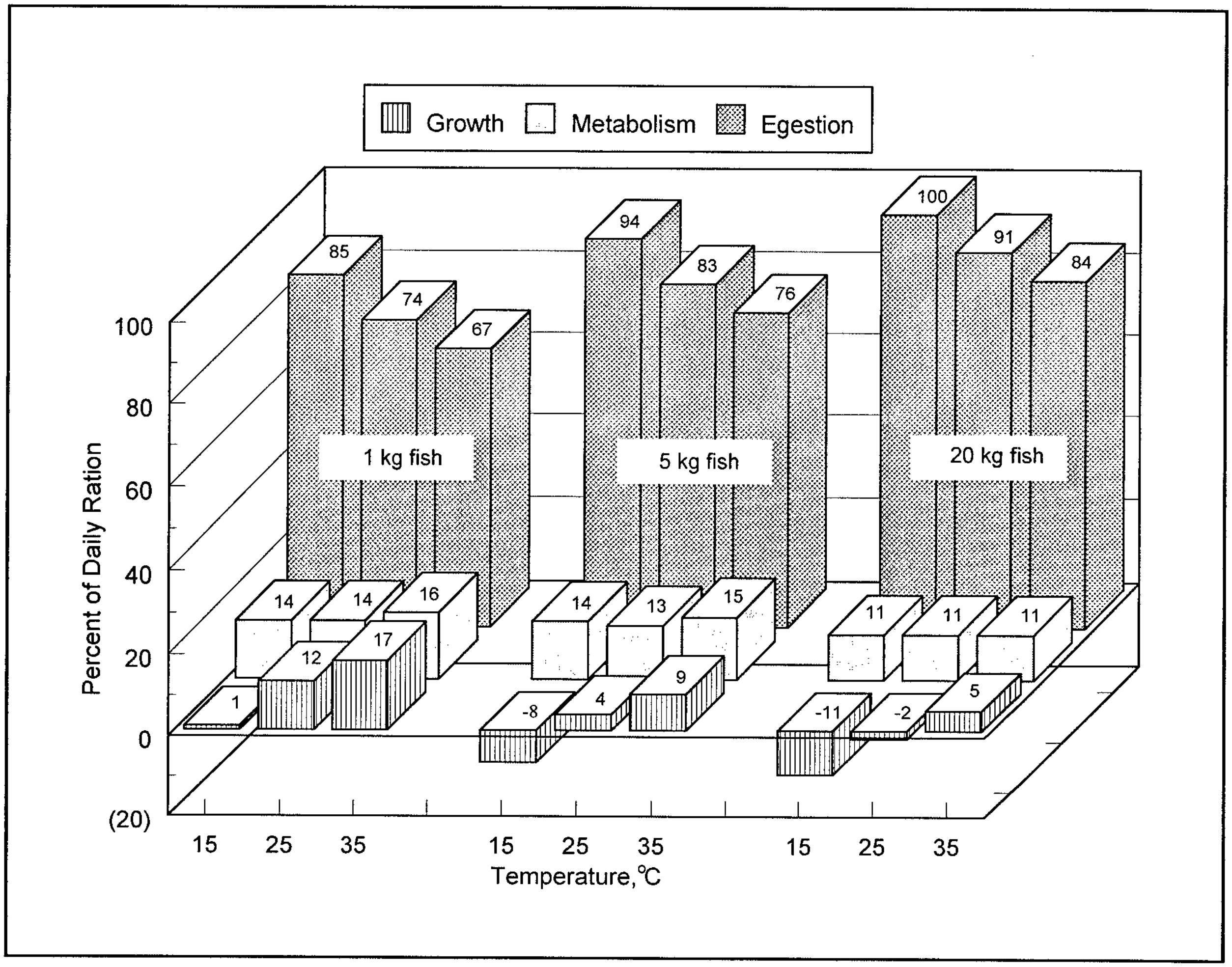

Figure 4. Relationship between bioenergetic balances and fish body size and temperature. Bioenergetic balances are based on the percent of daily consumption lost through egestion, utilized for metabolism, or available for growth

Initialization of the grass carp module includes inputs for the number, average size, and ploidy of grass carp to be stocked. Next, for each year of the simulation period, the user inputs percentage estimates for both fish mortality and escapement from the treatment area.

The primary outputs of the model are:

a. Estimates of plant biomass density (biomass/area) for each month of a 12-month seasonal growth cycle. For a given simulation run, the model assumes that plant growth follows the same growth curve for each year of the simulation period.

b. Total number of stocked fish remaining at the end of each poststocking year.

c. Average size of remaining grass carp at the end of each poststocking year.

d. Number of hectares (or acres) of plant growth controlled each year of the stocking period (up to 10 years) by herbivory from the stocked fish.

After first generating the above outputs, the model next calculates a Year 1 stocking rate (fish per vegetated hectare) needed to control plant growth in each year of the simulation period. For example, consider a simulation under which 1,000 grass carp stocked in Year 1 were estimated to control 10 hectares of vegetation at the end of Year 1, 50 hectares by Year 2, 100 hectares by Year 3, 200 hectares by Year 4, and 250 hectares by Year 5. Final model calculations would estimate that initial stocking rates of 100 fish per vegetated hectare would provide control by the end of Year 1. If control objectives were to obtain control within the first year, a stocking rate near this level would be considered appropriate for the simulation conditions. However, if control objectives provided that control was not necessary until the fifth post-stocking year, then initial stocking rates could be reduced to 4 fish per vegetated hectare (i.e. 1,000 fish stocked @ 250 hectares controlled by Year 5).

DEMONSTRATION OF MODEL USE: Simulation outputs for three sets of conditions will be presented to demonstrate use of the model.

Model Initializations. Seasonal temperature curves for the three sets of simulation conditions are illustrated in Figure 5. Note especially differences within the three curves during which water temperatures were below 11 °C, the lower threshold temperature for grass carp feeding. Each

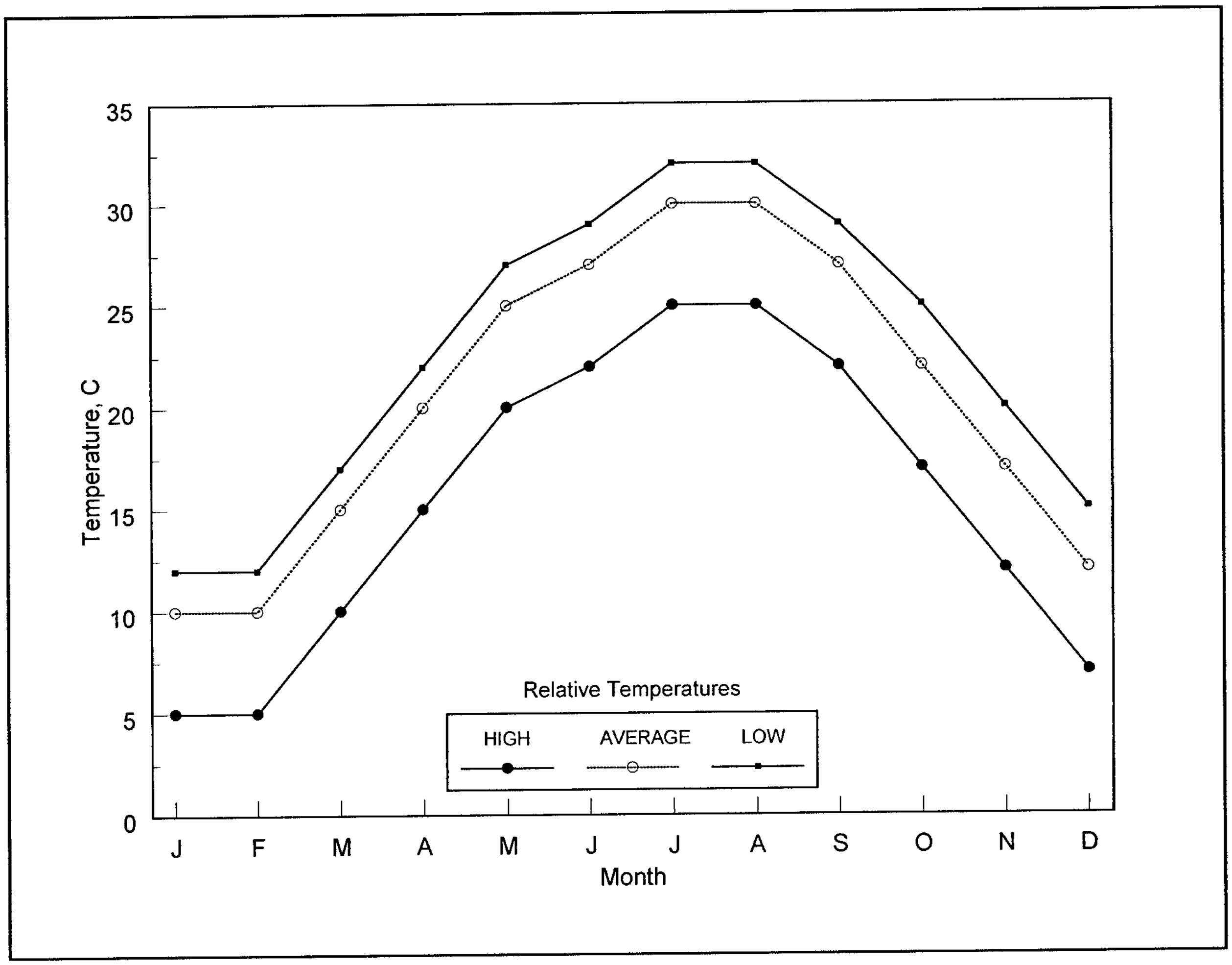

Figure 5. Three different seasonal temperature curves used to initialize the model for the three demonstration scenarios: Scenario 1 (HIGH), Scenario 2 (AVERAGE), Scenario 3 (LOW)

simulation run was executed for a 10-year period. Plant initialization conditions (Table 3), which varied among the three simulation scenarios, were selected as representative of conditions that result in highly problematic (Scenario 1), moderately problematic (Scenario 2), or slightly problematic (Scenario 3) levels of plant growth. Overwintering biomass levels considered herein were 12 g/m^2, 25 g/m^2, and 50 g/m^2. The lower level was selected to represent plant colonies in which the majority of shoot material generated during the growing season is lost through senescence prior to spring regrowth or by other processes (e.g. hydrological damage, control application). The highest overwintering level is representative of well-established plant colonies that overwinter with portions of their shoot material intact. Peak biomass levels for the three different plant growth conditions considered in the simulations ranged from 220 g/m^2 (slightly problematic) to 450 g/m^2 (highly problematic). These values equate on a fresh weight basis to approximately 22 and 45 metric tons per hectare, respectively. In field situations, differences in peak biomass levels could result from differences in plant species, or for a given plant species due to differences in colony age, prior treatment history, or for a list of environmental factors including water depth, light availability, and sediment nutrient levels. All simulations additionally considered that the target plant was *Hydrilla verticillata*, a plant that ranks highly on most feeding preference lists of grass carp (Sutton and Van Diver 1986, Leslie et al. 1987). For each simulation run, grass carp were stocked in April of Year 1. Average size of stocked fish was 0.34 kg, an estimate of the average weight of 30-cm fish (Kirk et al. 1996). Fish losses were assumed to be from mortality only, and were estimated at 10 percent annually.

Table 3
Initialization Values for Demonstration Scenarios

Parameter	Scenario 1	Scenario 2	Scenario 3
General parameters			
Duration, years	10	10	10
Temperatures	High	Average	Low
Plant parameters			
Overwintering biomass, g/sqm	12	25	50
Peak biomass g/sqm	220	330	450
Relative growth rate	Normal regrowth, initiated in April	Delayed regrowth, initiated in June	Delayed regrowth, initiated in July
Grass carp feeding preference	High	High	High
Grass carp parameters			
Number	1,000	1,000	1,000
Stocking size, kg	0.34	0.34	0.34
Mortality, %/yr	10	10	10
Escape, %/yr	0	0	0

Simulation Outputs. Seasonal plant biomass curves for the three sets of simulation conditions are shown in Figure 6. As stated previously, these particular growth curves were utilized so that

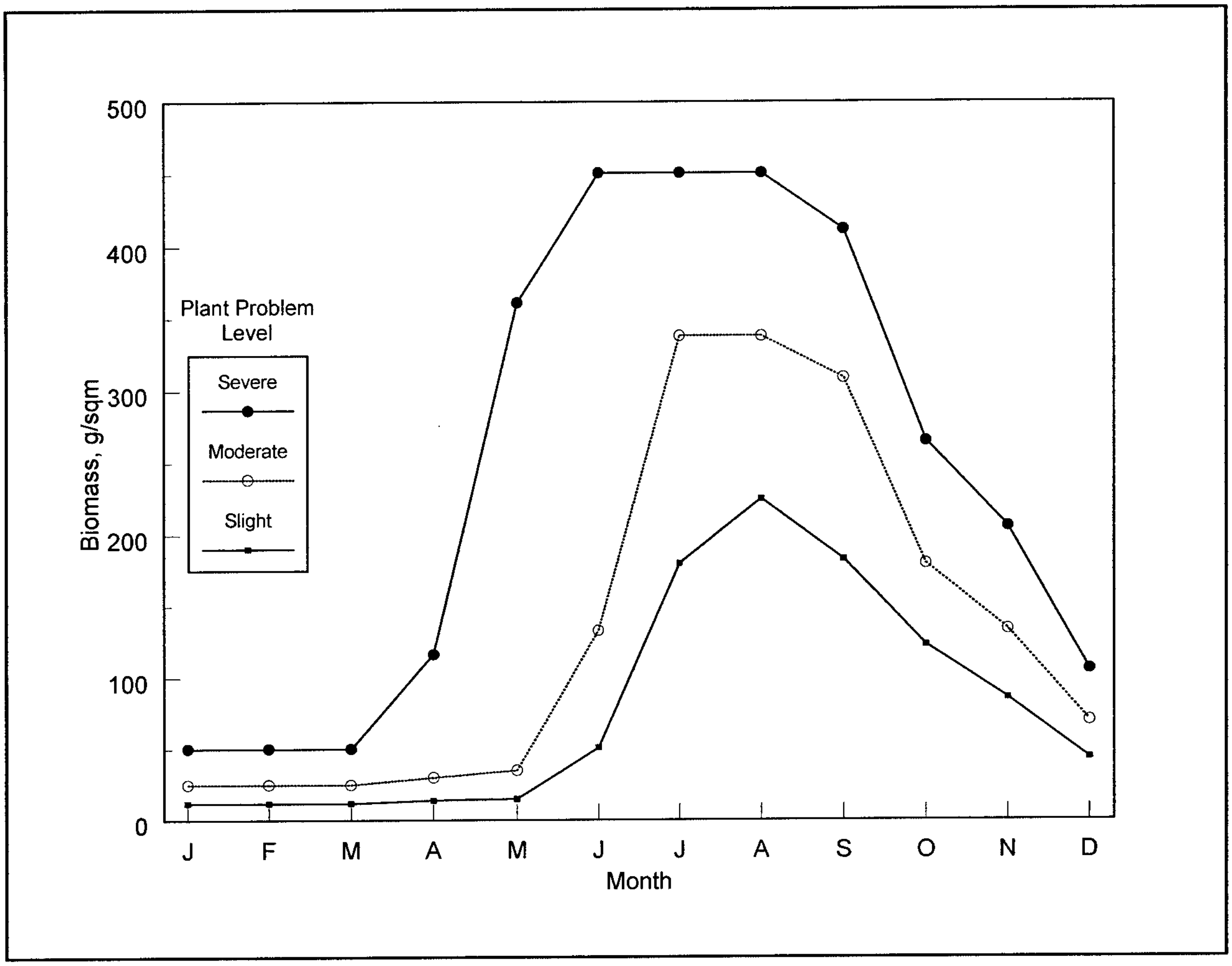

Figure 6. Three plant growth curves generated by the model for the three demonstration scenarios: Scenario 1 (SEVERELY PROBLEMATIC), Scenario 2 (MODERATELY PROBLEMATIC), Scenario 3 (SLIGHTLY PROBLEMATIC)

grass carp stockings could be evaluated for three operational scenarios, based on different seasonal temperatures and plant growth levels.

Outputs for Scenario 1 conditions, which included the highest seasonal water temperatures (Figure 5: HIGH) and the highest overwintering and peak biomass levels (Figure 6: SEVERELY PROBLEMATIC), are shown in Table 4. Due to annual fish mortality, actual numbers of fish declined from the 1,000 initially stocked to 387 by the end of Year 10. Fish grew rapidly, attaining weights greater than 20 kg by the end of Year 4. This rapid growth rate occurred because water temperatures never fell below the lower temperature for fish feeding, set in the model at 11 °C. Excessive size of fish by the end of the simulation period indicates that consumption rates for larger fish are probably too high in the model. Hectares of vegetation controlled by the stocked fish increased rapidly (from 2 to 35) in the first 4 years. Thereafter, control by the stocked fish remained near 40 hectares for the remainder of the 10-year period, indicating that losses from mortality were offset by increases in fish size. For conditions considered under Scenario 1, these results indicate that stocking rates near 500 fish per vegetated hectare would be needed to control plant growth by the end of Year 1, while Year 1 stockings of only 29 fish per vegetated hectare would be required if control were not needed until the fourth post-stocking year.

Table 4
Model Outputs for Scenario 1 Simulation Conditions

Post-Stocking Year(i)	Number of Fish at Beginning of Year[1]	Average Size of Fish, kg	Hectares Controlled	Stocking Requirement[2]
1	1000	3.5	2	500
2	900	10.4	16	62
3	810	16.9	29	34
4	729	22.0	35	29
5	656	26.2	39	26
6	591	29.8	41	24
7	531	33.1	41	24
8	478	36.3	41	24
9	430	39.4	40	25
10	387	42.6	39	26

[1] Numbers based on initial stocking of 1,000 fish with 10 percent losses annually from mortality and escape.
[2] The Year (1) stocking rate (fish per vegetated hectare) required to control 1 hectare of vegetation in each following year.

Outputs for Scenario 2 conditions, which included average seasonal water temperatures (Figure 5: AVERAGE) and average overwintering and peak biomass levels (Figure 6: MODERATELY PROBLEMATIC), are shown in Table 5. Due to identical fish mortality rates, fish numbers were identical to Scenario 1 outputs. However, because water temperature conditions were cooler than under Scenario 1 conditions, fish grew significantly slower, and attainment of 20-kg weight was delayed until Year 6. Even though fish grew slower and were therefore smaller in any given year, they provided greater control than fish under Scenario 1 conditions since the plants were also growing at significantly lower rates. Control provided by the stocked fish under these conditions increased from 7 hectares in Year 1 to near 50 hectares by Year 4. These results suggest that Year 1 stocking rates near 20 fish per vegetated hectare would provide plant control under similar conditions by the fourth or fifth post-stocking year.

Outputs for Scenario 3 conditions, which included the coolest seasonal water temperatures (Figure 5: LOW) and the lowest overwintering and peak biomass levels (Figure 6: SLIGHTLY PROBLEMATIC), are shown in Table 6. Fish numbers are identical to Scenarios 1 and 2. As temperatures were yet again cooler, fish grew slower and never attained body weights near 20 kg. Because fish growth was significantly lowered, annual increases in consumption due to fish growth were not sufficient to offset losses in consumption due to cumulative mortality. Therefore, even though plant growth levels were less under Scenario 3 conditions than under Scenario 2 conditions, control provided under Scenario 3 conditions was less in every year except the first year. Similar to Scenario 1 results, peak levels of control near 40 hectares were attained by Year 5. Unlike Scenario 1 results, however, control under Scenario 3 conditions began to decline after the seventh

Table 5
Model Outputs for Scenario 2 Simulation Conditions

Post-Stocking Year(i)	Number of Fish at Beginning of Year[1]	Average Size of Fish, kg	Hectares Controlled	Stocking Requirement[2]
1	1000	2.5	7	143
2	900	7.3	24	42
3	810	11.9	38	26
4	729	15.7	48	21
5	656	18.8	53	19
6	591	21.2	55	18
7	531	23.4	55	18
8	478	25.5	54	19
9	430	27.5	53	19
10	387	29.3	51	20

[1] Numbers based on initial stocking of 1,000 fish with 10 percent losses annually from mortality and escape.
[2] The Year (1) stocking rate (fish per vegetated hectare) required to control 1 hectare of vegetation in each following year.

Table 6
Model Outputs for Scenario 3 Simulation Conditions

Post-Stocking Year(i)	Number of Fish at Beginning of Year[1]	Average Size of Fish, kg	Hectares Controlled	Stocking Requirement[2]
1	1000	1.4	9	111
2	900	3.2	19	53
3	810	4.8	29	34
4	729	6.2	35	29
5	656	7.3	38	26
6	591	8.2	39	26
7	531	8.9	38	26
8	478	9.4	37	27
9	430	9.8	35	29
10	387	10.2	33	30

[1] Numbers based on initial stocking of 1,000 fish with 10 percent losses annually from mortality and escape.
[2] The Year (1) stocking rate (fish per vegetated hectare) required to control 1 hectare of vegetation in each following year.

post-stocking year. Still, results indicate that a Year 1 stocking rate of 29 fish per vegetated hectare should provide control of vegetation growing at levels considered under these conditions by the end of the fourth post-stocking year.

MANAGEMENT CONSIDERATIONS: Post-stocking time was the single most important factor affecting stocking rate requirements in these simulations. For the three sets of simulation conditions considered, stocking rate requirements varied by as much as 20 times depending on required effect time. These differences stem from the fact that as fish grow in size, fewer are required to provide the same level of control. As peak effectiveness of stocked fish is often delayed until the fourth year or more following stocking, stocking rates aimed at providing control within all target areas within the first few years following stocking will probably be too high. Results of such improper stocking would include both unnecessary costs for purchase of fish and possible detrimental ecological impacts to non-target areas. Exceptions to this are cases where complete elimination of vegetation is required, or heavy losses of stocked fish are expected.

Generally speaking, grass carp are effective only when they can consume more plant biomass than is produced by plant growth in the target area. Simulations included herein indicate that several plant growth characteristics should be considered when determining proper stocking rates. Important plant growth characteristics considered were overwintering level, onset and rate of regrowth, and peak biomass. Knowledge of each of these is required to determine a proper stocking rate. Similarly, manipulation of any of these plant growth characteristics will alter the effectiveness of stocked fish. For example, implementation of any plant control technique prior to spring regrowth will increase effectiveness of stocked fish during that growing season.

In addition to plant growth characteristics, grass carp growth rates and losses also affect stocking results. Variability in fish growth rates was shown herein to result from differences in water temperatures. Differences can also be affected by other factors, including plant nutritional value as determined by site conditions, or to plant species, which would determine preference to feeding by grass carp. Variability in loss rates is known to occur due to differences in grass carp health condition or size at stocking, or to differences in predator populations. Additionally, losses could also result from non-mortality based factors, such as off-target movement within the stocked waterbody or escape from the waterbody. No matter what the cause of grass carp losses, the net result is decreases in plant consumption and control effectiveness. Due to the likelihood of this occurrence in larger waterbodies, stocked fish have sometimes been enclosed within target areas (Leslie et al. 1987). In situations where actual losses will be high and cannot be reduced by stocking technique, higher stocking rates will be required for grass carp stockings to be effective.

SUMMARY: A complex set of interacting factors must be considered in order to determine proper grass carp stocking rates. The WES Stocking Rate Model was designed to help aquatic plant managers consider the effects of some of these factors. Examples presented herein illustrate the significance of poststocking time coupled with seasonal plant growth characteristics (i.e. overwintering and peak biomass levels and regrowth rates) and water temperature conditions.

POINTS OF CONTACT: For additional information on AMUR/STOCK, contact the senior author of this technical note, Mr. R. Michael Stewart (601-634-2606, *stewarr@wes.army.mil)* or the Managers of the Aquatic Plant Control Research Program, Dr. John W. Barko, 601-634-3654, *barkoj@wes.army.mil*, and Mr. Robert C. Gunkel, Jr., 601-634-3722, *gunkelr@wes.army.mil*. The

AMUR/STOCK model is currently being distributed on CD-ROM as part of the Aquatic Plant Information System (APIS). This technical note should be cited as follows:

> Stewart, R. M., and Boyd W. A. (1999). "The grass carp stocking rate model (AMUR/STOCK)," *APCRP Technical Notes Collection* (TN APCRP MI-03), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/apcrp*

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